THE UNIVERSITY OF ALBERTA

A COMPARISON OF FOUR METHODS FOR MEASURING LEG LIFT STRENGTH

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS

FOR THE DEGREE OF MASTER OF SCIENCE

FACULTY OF PHYSICAL EDUCATION

EDMONTON, Alberta

August, 1968

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "A Comparison of Four Methods for Measuring Leg Lift Strength," submitted by Thomas Michael Buck in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

Four methods of measuring the strength of the leg extensors were administered to twenty-four male volunteers from the freshman class at the University of Alberta. Each subject participated in the four tests after having been randomly assigned to one of twenty-four possible testing orders. Test A involved the use of the traditional belt and an experimental leg dynamometer with no restriction of lunging. Test B was the same as Test A except a vertical board was attached to the leg dynamometer to prevent lunging. Test C involved the use of an experimental bar and belt, the leg dynamometer, and the board to prevent backward lunging. The subjects were not allowed to use their hands in Test C but were instructed to let them hang by their sides. Test D was identical to Test C with the exception that the subjects were allowed to place their hands on the bar.

In addition to the above testing procedures an electrogoniometer was attached to the left leg of each subject during each test to measure knee angle throughout the test.

Analyses of Variance and Covariance showed significant differences among the means of the scores for the different tests.

An analysis of variance yielded significant differences among the means of knee angle changes for the different tests.

When the Newman-Keuls tests for all ordered pairs of means were used, significant differences were found between Test A and Test C.

A definite pattern in the ascending order of means was noted. Means for tests always ascended from low to high in the order of Test C, Test B, Test D, Test A.

Test Method C was found to have the least standard error of measurement.

ACKNOWLEDGEMENTS

I would like to express my appreciation to the following people who have assisted me in the completion of this study.

To the members of my committee, Dr. S. Mendryk (Chairman), Dr. M. Singh, Dr. R. B. J. Macnab, and Dr. J. E. Bicknell, I would like to extend my sincere thanks.

I would also like to acknowledge the financial and technical assistance provided by the Fitness and Amateur Sport Directorate, Government of Canada, in the construction of the apparatus.

Appreciation is also expressed to Mr. Harold Cartlege for assistance in the analysis of the data, Miss Norma MacDonald for typing the manuscript, and Mr. Ed Wagner for illustrating the apparatus.

Sincere thanks go to my family, Jane, Peter, and Heidi, who have willingly accepted many responsibilities and who have always been a source of encouragement.

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

Measures of leg strength have been used in various ways for nearly a century. Strength testing in general, however, is not a new concept since most cultures throughout history have used feats of strength and trials of endurance as a measure of physical condition. Methods of measuring strength have varied, but since Dr. Dudley Sargent developed the Intercollegiate Strength Tests in 1873 and included a measure of leg strength, a form of this particular test has remained in use up to the present time (4).

During the early part of the twentieth century strength tests were not used, probably because of beliefs that their contribution to the evaluation of an individual's physical status was too limited as they did not contribute as much as tests of physical endurance and determinations of heart and lung development. Work by Dr. Frederick Rogers in 1925 did much to reinstate the measurement of strength in physical performance test batteries. Rogers improved Sargent's original test battery by standardizing the testing procedures and by establishing norms.

Rogers' test battery included the following items: right and left grip strength, leg lift, back lift, pull ups, push ups, and lung capacity using a wet spirometer. By constructing norm tables Rogers created the Physical Fitness Index (P.F.I.). The P.F.I. is determined by comparing the Strength Index (S.I.), a gross score obtained from the

strength and lung capacity tests, with norm tables. An individual's S. I. score is divided by a norm score and the quotient is multiplied by 100 thereby determining the P.F.I.

Several authors have presented more detailed histories of strength testing, including: Clarke (2), Martin (3), Mathews (4), and Willgoose (5).

The test of leg strength in the Rogers battery was named the leg lift. The leg lift can best be described as a test of the strength of the leg extensors as registered on a dynamometer during the performance of a vertical lifting movement. The leg dynamometer used in the administration of the leg lift test is usually mounted on a small platform on which the subject stands with his feet about six inches apart. A steel bar about twenty inches long and one inch in diameter is secured to the subject's hips at about the level of the pubic bone by means of a simple canvas belt. The belt is looped around one end of the bar and then passed around behind the subject so that it comes to rest as low as possible on the gluteal muscles. The free end is then looped around the bar and tucked under so that it rests against the body. At the midpoint of the bar is a strong hook. A chain from the dynamometer is attached to this hook after the subject has flexed at the knees to make an angle between 115 degrees and 125 degrees. The subject is instructed to grasp the bar, keep his back and arms straight, keep his head erect and his chest up, and to lift by driving his legs downward as hard as he can. The maximum strength score of at least two trials is read from the dynamometer to the nearest five pounds and is recorded (2), (4), (5).

The procedures as outlined above have undergone some change

from those originally recommended by Rogers for use with the P.F.I. A further discussion of those changes will appear in Chapter II.

The Problem

Although there have been several suggestions leading to the improvement of the leg lift technique since the test was originally developed, there are still factors involved with the test that raise doubts as to its validity. Although the belt now used helps to secure the bar to the subject there may still be a contribution to the lifting score made by the hands and arms. Furthermore, there is little information regarding the angle at which the test should be administered, though Carpenter (1) has recommended an angle of between 115 degrees and 124 degrees. Test directions (2), (4), (5) usually state that the angle of the legs will change during the test and that the maximum lift will occur by the time the legs are almost straight. Research in general dealing with the leg lift strength test subsequent to Rogers' study is lacking.

This study will be concerned with determining whether or not there is a significant difference between scores when the hands are allowed to grasp the bar and when a new belt that fastens securely to the hips is used without hands. A sub-problem will be to measure continually the subject's knee angle by means of an electrogoniometer to first determine the change in angle at the knee and, second, to determine at which angle the greatest lift occurred. Four different methods of administering the leg lift test will be compared.

The null hypotheses for the problem are:

1. That the means of the four groups shall be equal.

Ho: $u_A = u_B = u_C = u_D$

2. That the means of the four trials shall be equal.

Ho: $u_1 = u_2 = u_3 = u_4$

3. That the lift scores are independent of knee angle change.

Ho: No interaction between score and angle.

4. That the mean angle changes of the four tests shall be equal.

Ho: $u_{aA} = u_{aB} = u_{aC} = u_{aD}$

Limitations of the Study

The study is limited to twenty-four first year, male, volunteers from two physical education service program classes at the University of Alberta.

Definition of Terms

Leg Lift. A test of the strength of the extensor muscles of the leg at the knee by having the subject lift vertically and maximally with his legs and recording the lift score on a leg dynamometer.

Backward Lunge. A quick, forceful backward impulse at the hips while the leg extensors are at maximum tension, causing a resultant force to be measured on the dynamometer that is not primarily a lifting force.

Traditional Leg Lift Method. The leg lift test using a simple canvas belt, a steel bar about twenty inches long and one inch in diameter with a strong hook attached at the midpoint on the bar, a length of chain, and a leg dynamometer. For this study the canvas belt and the bar will be used.

<u>Experimental Leg Lift Method</u>. The leg lift test using the experimental belt and bar and the new leg dynamometer.

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3. Martin, E. G. "Tests of Muscular Efficiency," Physiological Review, 1:454-475, 1921.

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CHAPTER II

REVIEW OF THE LITERATURE

The leg lift test as used at the present time had its beginnings in the Rogers Test Battery in 1925. Since that time the entire battery has been used by schools, Y.M.C.A.'s, colleges, and universities. During the past four decades there have been only three studies dealing specifically with the leg lift technique. These studies are discussed below and are arranged according to the subject with which they were concerned.

Knee Angle

Instructions for the administration of the leg lift test have appeared in many books dealing with measurement in physical education (2) (6) (7) (9). One of the earliest books was written by Rogers (7), in which he suggests that the leg lift be performed at an angle between sixty and ninety degrees. A later study by Carpenter (1) was designed to determine which angle at the knee afforded the greatest lift. Carpenter (1) subjected thirteen women and seven men to the leg lift test six times a day for eighteen days, with the six lifts being made at six different angles. The order of the angles at which a subject would lift was changed daily so that no angle would always come first or last. When an individual had completed all of his tests his best score at any angle was designated as 100 per cent for him. All other scores for that individual were then divided by his highest score in order to determine a percentage. Carpenter (1) concluded that the maximum in leg lift is obtained when the thighs and lower leg make an

angle at the knees between 115 degrees and 124 degrees. Angles between 125 degrees and 139 degrees ranked second. Anything less than 115 degrees or greater than 139 degrees was considered to be definitely inferior.

Willgoose (1) states that the maximum lift should occur when the subject's legs are almost straight at the end of the lifting effort but does not give a reason for this statement. Mathews (6) and Clarke (2) make similar statements.

Karpovich and Karpovich (5) have developed an electrogoniometer to study joint movement. Basically, the electrogoniometer consists of a round rheostat with two shafts attached. The electrogoniometer is attached to the joint in such a way that the shafts follow the bones making up the joint while the round rheostat rests on the joint itself. A more detailed description of the electrogoniometer is given in Chapter III.

<u>The Belt</u>

The leg lift test was originally designed to be administered without the aid of a belt to secure the bar at the level of the subject's hips. Critics of the leg lift test method suggested the use of a belt to take the strain of the lift (8) but no actual method employing a belt was produced until 1938 when Everts and Hathaway (3) published the results of a study showing the improvement of the test by the use of a belt. Everts and Hathaway (3) claimed that the use of a belt increased test validity by making it possible to obtain higher scores. Formerly, the authors stated, it was difficult to adjust the crossbar to the thighs of individuals who varied in height and weight, subjects were often bruised, it was almost impossible for women to

administer the test, and it was impossible to hold the bar for the stronger subjects.

The first belt was made from heavy, tightly woven, canvas belting. A permanent loop was made at one end of the belt and from then on it was used in testing as described in Chapter I. Further instructions were also given for the use of the belt when testing individuals varying widely in build. According to Everts and Hathaway (3), the advantages of the belt were increased accuracy in measurement, increased confidence on the part of the subject, greater safety, elimination of testing errors, more advantageous testing of female subjects, and the elimination of the need for the wearing of gymnasium uniforms while being tested.

<u>Prevention of Back Lunge</u>

After the studies by Carpenter (1) and Everts and Hathaway (3) there was no major change in the technique of measuring leg lift strength until Hubbard and Mathews (4) in 1953 challenged the Everts-Hathaway (3) study. Hubbard and Mathews (4) state, " . . . the subject may be aided by the belt in getting a vertical, or lifting, component." This spurious, non-lifting force would be the result of the extensor muscles being at maximum tension, causing the lower limb from hip to ankle to act as a fixed lever. The ratio of the hip to ankle distance to the ankle to dynamometer distance would be sufficient to cause a considerable increase in the lift score when in fact, the contribution to the lift score is not actually a vertical component. To prove their hypothesis Hubbard and Mathews (4) used seventeen subjects under four different testing conditions. Lifting without the aid of a belt the subjects were instructed to lift as hard as possible and then to lunge

backward. The subjects were then retested with their buttocks against a smooth wall to prevent any backward lunge. The same tests were repeated with the addition of the belt. The knee angle was kept at about 120 degrees for all tests. The tests were given over a period of two weeks with test days being Mondays and Thursdays. Testing orders were varied to equate intraserial practice and fatigue effects. An analysis of variance of the four lifting conditions gave a value of F which was significant beyond the .01 level. Mean scores under conditions A, B, C, and D, were respectively, 685.0, 751.1, 1001.8, and 1372.6 pounds. Lunging backward without the belt produced only small increases in scores while the additional force while lunging with the belt averaged about 375 pounds. Hubbard and Mathews (4) state that leg lifts as measured without the belt may depend on the ability to hold the bar at the hip level both with and without the back lunge occurring. Inability to hold the bar at the hips was probably eliminated by using the belt but the ability to increase the score by developing a back lunge was enhanced. The authors concluded that the non-lifting component can probably be prevented by forcing the subject to slide his buttocks up a smooth wall as he lifts.

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CHAPTER III

METHODS AND PROCEDURES

Subjects

Twenty-four first-year, male volunteers from two physical education service program classes at the University of Alberta were used as subjects. The subjects were randomly assigned to twenty-four different testing orders so that no two testing orders were identical. The subjects were enrolled in the faculties of Arts, Commerce, Education, and Science.

Experimental Design

Each subject was tested on four different days using a different testing method each day. Subjects were tested as near as possible on consecutive days and at the same time during the day. In order to eliminate any activity that might have prevented a maximal lift the subjects were excused from their physical education classes during the period of time that they were being tested and were asked to avoid any other strenuous exercise. Four different trials were allowed with one minute rest periods between trials. All scores were recorded as well as the changes in knee angle throughout the lift.

Anthropometrical Data

The following anthropometrical data was collected from each subject: age (years and months); height (inches); weight (pounds).

Procedures for Administering the Tests

There were four different tests administered to each subject

which were simply known as Tests A, B, C, and D. The subjects were not aware of the actual purposes of the experiment. Test A, as shown in Figure 1, involved the use of the traditional belt and the experimental leg dynamometer with no restriction of backward lunge. Test B, shown in Figure 2, was the same as Test A except the vertical board on the leg dynamometer was used to prevent backward lunging. Test C is shown in Figure 3. Test C involved the use of the experimental bar and belt, the leg dynamometer, and the vertical board to prevent backward lunging. The subjects were not allowed to use their hands in any way on Test C but were instructed to let them hang at their sides. Test D, shown in Figure 4, was identical to Test C with the exception that the subjects were allowed to place their hands on the bar.

In addition the electrogoniometer was attached to the left leg of each subject for each test to measure changes in angle throughout the test. The electrogomiometer was placed on the lateral side of the left leg so that the rheostat rested on the lateral epicondyle of the femur with the shafts connecting with the midpoint of the greater trochanter and the midpoint of the lateral maleolus. The electrogoniometer was secured with adhesive tape.

With the bar secured at the level of the subject's pubic bone and the knees flexed at an angle of 120 degrees the subject was asked to lift straight up by driving his feet into the dynamometer base, and at the same time to keep his back and arms straight, his head erect, and chest up. When backward lunge was prevented the subject was held against the vertical board arising from the leg dynamometer by means of a seat belt which passed across his chest. The subjects were told that it was important that they lift as hard as possible and were encouraged

FIGURE 1

SUBJECT PERFORMING TEST A USING THE TRADITIONAL
BELT WITH NO RESTRICTION OF BACKWARD LUNGE

FIGURE 2

SUBJECT PERFORMING TEST B USING THE TRADITIONAL BELT
WITH LUNGING CONTROLLED BY THE VERTICAL BOARD

FIGURE 3

SUBJECT PERFORMING TEST C USING THE EXPERIMENTAL BELT WITHOUT HANDS, WITH LUNGING CONTROLLED BY THE VERTICAL BOARD

FIGURE 4

SUBJECT PERFORMING TEST D USING THE EXPERIMENTAL
BELT AND HANDS, WITH LUNGING CONTROLLED
BY THE VERTICAL BOARD

to lift before and during each trial. All tests were administered by the writer.

Experimental Apparatus

Leg Dynamometer. The experimental leg dynamometer is illustrated in Figure 5. The dynamometer consisted of a two-horse power electric three phase motor connected by means of a flexible coupling to a Vickers eighteen gallon per minute vane pump, to a positive filter, to a directional control valve which enabled a double-acting hydraulic cylinder to move forward or backward, or stop. The hydraulic cylinder had a three-inch diameter and a thirty-inch stroke. Connected to the cylinder was a cylinder rod and connected to this was a three thousand pound capacity cable. The cable passed over two ball bearing pulleys so as to pass out and up from the machine at a point directly between the subject's feet. The cable was connected to the subject by means of a belt and bar.

The construction of the dynamometer allowed the administrator to adjust the length of the cable so that each subject began his tests at a knee angle of 120 degrees.

Directly behind where the subject stood was attached a solid plywood back support (vertical board) extending from one foot above the platform of the machine to seven feet. The surface of this back board was waxed to help eliminate friction and a piece of smooth Arborite was affixed to the area where the belt would come in contact with the board to further reduce friction and prevent splintering of the board. On each side of the board were mounted steel rods on which ball-bearing sleeves travelled. Connected to each ball-bearing sleeve was half a car seat-belt so that the subject could be strapped to the

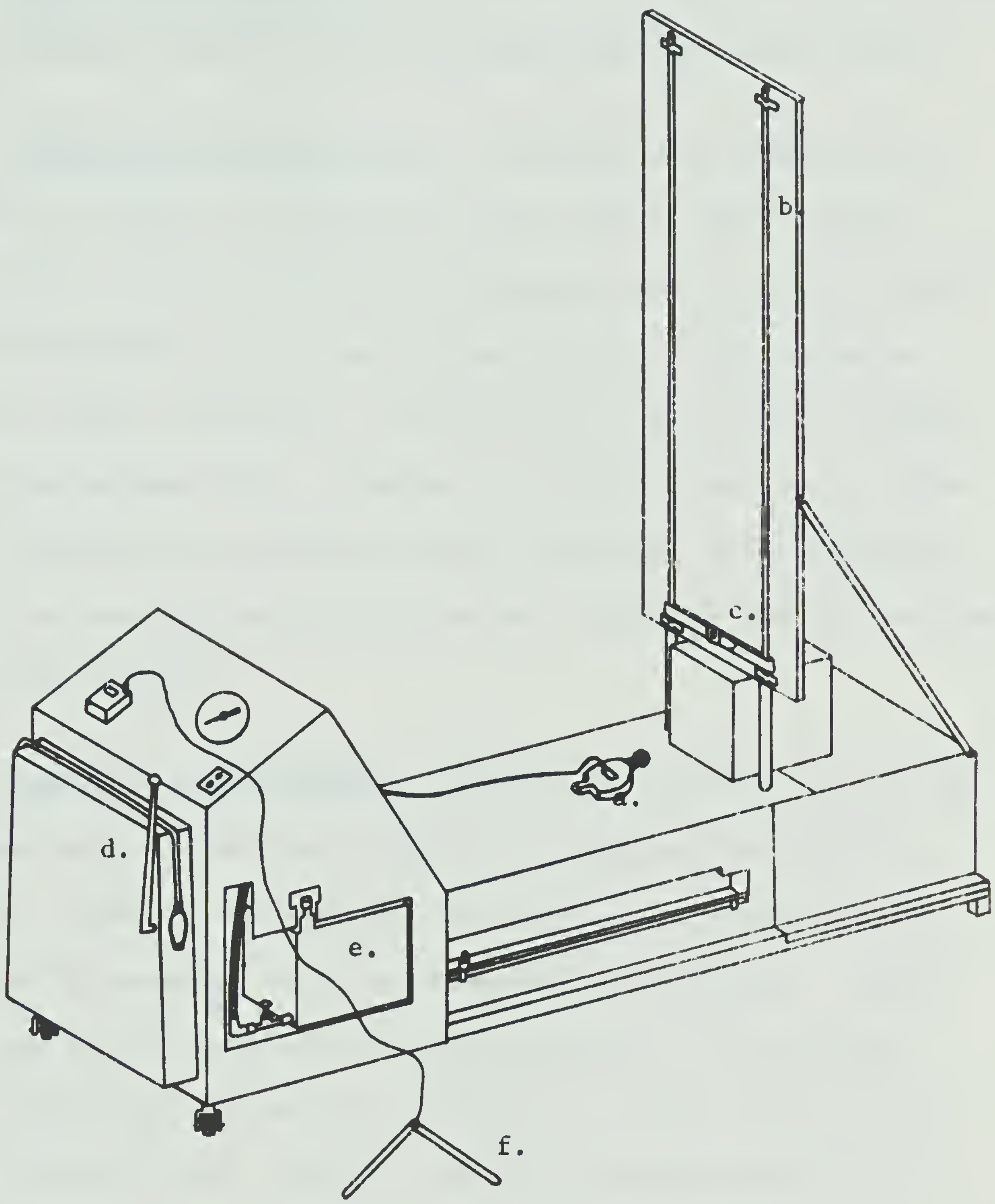

FIGURE 5

EXPERIMENTAL LEG DYNAMOMETER

a. Load Cell and Cable b. Vertical Board c. Restraining Belt d. Cable Length Adjustment Switch e. Vane Pump f. Electrogoniometer

board but could still move up and down.

Traditional Bar and Belt. A bar and canvas belt usually used for the traditional leg lift test were also used for Tests A and B.

Experimental Bar and Belt. The especially designed belt, illustrated in Figure 6, consisted of a bar with a safety release mechanism which could be pulled by the subject had he felt any pain or unbearable discomfort at any time during the test. The mechanism released the cable from the bar. The bar itself was firmly attached to a four-inch webbed belt. Attached to the webbed belt was a nylon automobile seat-belt with safety-release mechanism. By closing the buckle of the seat-belt and pulling the belt tight the bar and belt were secured to the subject.

Load Cell and Dynograph. Attached to the cable and bar was a 3000 pound capacity load cell, model U 31 tension type from BLH Electronics. Power to and from the load cell was provided through a Beckman Type RS Dynograph with two channels for recording. Signals from the load cell were received by and recorded on the dynograph which was calibrated to move one millimeter for every 100 pounds of tension on the load cell. Signals from the electrogoniometer were recorded on the other channel of the dynograph which was calibrated to move one millimeter for two degrees of change in angle.

Sargent Recorder (Model SR). The signals received on the dynograph were simultaneously amplified on a Sargent recorder. This machine was calibrated to 3000 pounds pull and the pounds pull was read as a percentage of 3000 pounds. Accuracy to within three pounds

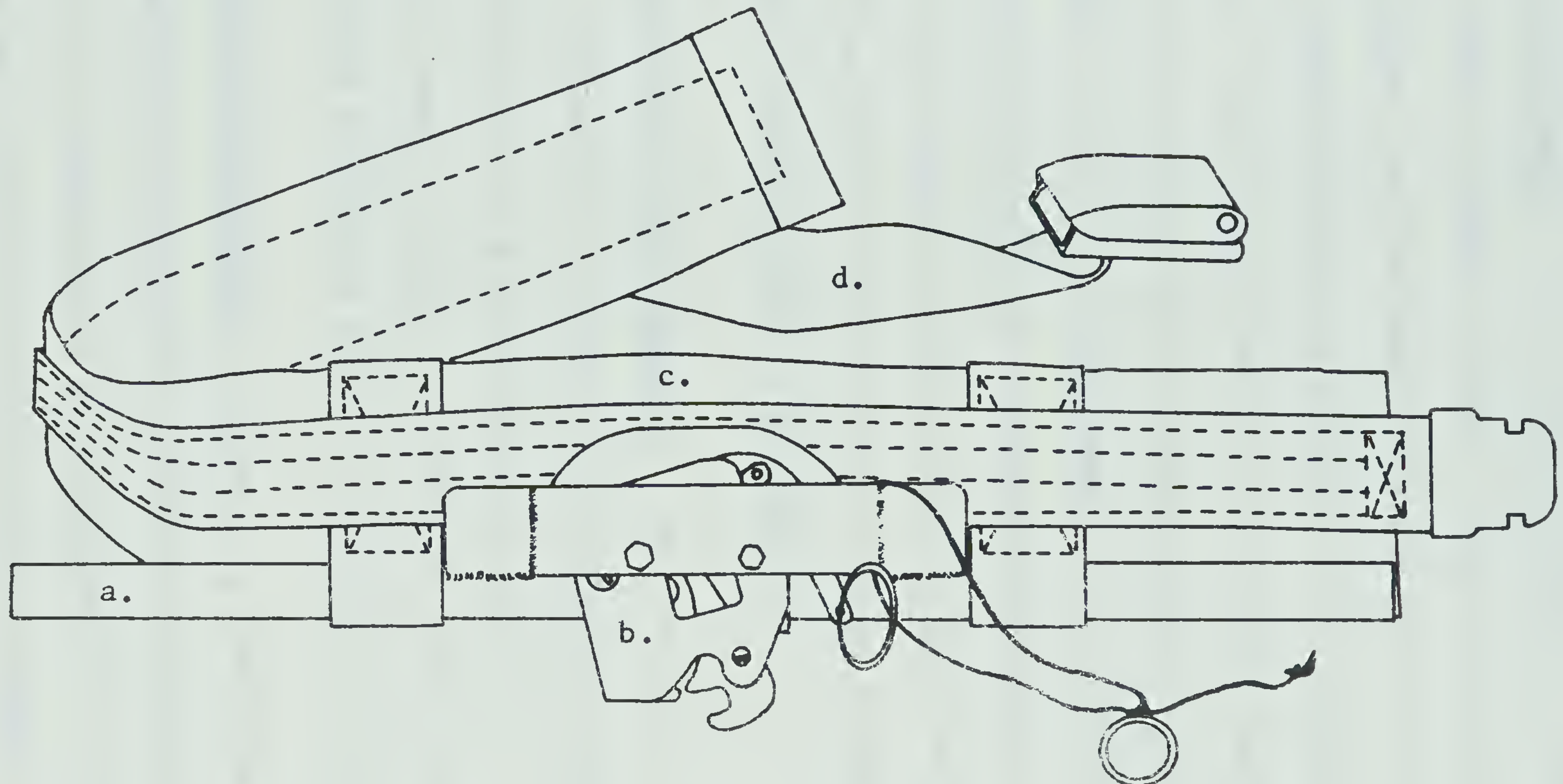

FIGURE 6

EXPERIMENTAL BAR AND BELT

a. Bar b. Safety Release Mechanism c. Four-inch Webbed Belt

d. Automobile Seat Belt.

could be achieved by interpolating to tenths of divisions and without interpolation the machine was accurate to within thirty pounds.

Electrogoniometer. The electrogoniometer consisted of a second rheostat with two plastic shafts. The rheostat portion of the goniometer was placed over the lateral epicondyle of the femur with the two shafts connecting with the midpoint of the greater trochanter and the midpoint of the lateral maleolus. The electrogoniometer was connected by wire to a meter, which in turn was connected to the dynograph. Power for the electrogoniometer was supplied by a small battery. For calibration purposes the electrogoniometer was secured to a protractor with adhesive tape so that one shaft was immobilized while the other was free to move causing a change in angle. Calibration procedures are described in Appendix F.

Calibration of the Apparatus. The load cell, dynograph, and enlarger were calibrated by comparing the indicated deflection on the graph with a known load on a strain-gauge calibrated accurate to two pounds. For the Sargent enlarger a 3000 pound pull was set to 100 per cent and lesser pulls were read as a percent of 3000 pounds.

Statistical Treatment. Reliability coefficients were computed using analysis of variance to estimate reliability of measurements. The standard error of measurement was computed for each test method. Correlations between lift score and knee angle changes were determined. The significance of the differences among the means of the four tests was computed using an analysis of variance technique. In addition an analysis of covariance was also used with knee angle held constant. The significance of the differences among the means of the knee angle changes on the four tests was computed using analysis of variance.

CHAPTER IV

RESULTS AND DISCUSSION

The analysis of the data is presented in the following order: reliability coefficients; standard error of measurement; means of trials by tests; analyses of variance and covariance using all scores; correlations between tests and knee angle changes; analyses of variance and covariance using maximum scores; analyses of variance and covariance using average scores; Newman-Keuls tests on the differences between ordered pairs of means; and analysis of variance on changes in knee angle. For this study the .05 level of confidence was set as the level at which differences between means would be interpreted as significant. In addition, significant differences beyond the .05 level will be reported.

The statistical techniques listed above were employed to test the hypotheses stated in Chapter I. The hypotheses were:

1. That the means of the four tests shall be equal.
2. That the means of the four trials shall be equal.
3. That lift scores are independent of knee angle change.
4. That mean angle changes of the four tests shall be equal.

The following reliability coefficients were determined on all subjects for each testing method using analysis of variance to estimate reliability of measurements (4:124-131).

TABLE I

RELIABILITY COEFFICIENTS

Test	Reliability Coefficients
A	.89
B	.97
C	.97
D	.95

The reliability coefficients are test-retest correlations and make no indications as to the precision of an individual's score. A further contribution to the interpretation of test reliability is made by the use of a standard error of measurement technique which is an estimate of the standard deviation of a series of measurements on the same individual. The formula used for the standard error of measurement is discussed by Thorndike and Hagen (3:183) and is shown in Appendix B. The reliability coefficients used in the computation of the standard error of measurement are displayed in Table I while the standard deviations are shown in Table III. Table II shows the standard error of measurement for each test.

On the basis of the standard error of measurement results as displayed in Table II it can be seen that scores using Test A can be expected to vary ± 172.02 pounds, scores on Test B ± 79.56 pounds, scores on Test C ± 68.24 pounds, and scores on Test D ± 112.82 pounds. Within the limits of these results the most accurate scores are obtained using Test Method C since the lowest standard error of measurement occurs with that test method.

[illegible]

[illegible]

[illegible]	[illegible]
[illegible]	
[illegible]	
[illegible]	
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[illegible]

[illegible]

[illegible]

TABLE II

STANDARD ERROR OF MEASUREMENT-SUMMARY

Test	S_m	Tolerance
A	86.01 pounds	$\pm$ 172.02 pounds
B	39.78	$\pm$ 79.56
C	34.12	$\pm$ 68.24
D	56.41	$\pm$ 112.82

Table III is a display of the means of all trials for each test and is based on the raw data as presented in Appendix A.

TABLE III

MEANS OF TRIALS BY TESTS

		Tests			
		A	B	C	D
Trials	1	976.42	814.21	735.00	846.13
	2	959.58	773.17	718.08	802.46
	3	981.21	817.79	762.88	829.29
	4	1014.71	874.75	808.83	913.00
General Means		982.98	819.98	756.19	847.72
General σ		259.38	229.67	196.98	252.27

A definite pattern can be observed in Table III where the ascending order of means from low to high is always the same for each trial. The ascending order is Test C, Test B, Test D, Test A. The same order is apparent for the General Means and for the General

Standard Deviations.

On the basis of the observed differences among means in Table III analyses of variance and covariance were carried out to determine whether the observed differences were significant.

TABLE IV

ANALYSIS OF VARIANCE-SUMMARY

ALL SCORES

Source	Sums of Squares	df	Mean Squares	F
Subjects	10,937,980.00	23	475,564.35	26.51 * **
Subjects within trials	1,291,793.13	72	17,941.57	
Tests	2,628,185.06	3	876,061.69	64.89 * **
Subjects x Tests	5,989,404.56	69	86,802.96	6.43 * **
Residual	2,915,868.88	216	13,499.39	
Total	23,763,231,63	383		

* significant at .05 level

** significant at .01 level

	df	.05	.01
	23,72	1.68	2.11
F=	3,216	2.65	3.88
	69,216	1.39	1.58

The results of the analysis of variance using all scores are summarized in Table IV. Analysis of variance using all scores yielded highly significant F values for subjects, tests, and subjects by tests interaction. The significant F value for subjects was expected since performances among subjects can be expected to vary on the basis of individual differences. No particular cognizance is taken of the fact

that differences among subjects were found except that the differences help to reduce the error term. The lack of a significant F value for subjects within trials is in harmony with the reliability coefficient values presented in Table I. The highly significant F value for tests indicates that the differences between means observed in Table III are significant. The significant F value for subjects by Tests indicates that the performance of some subjects is affected by a particular test method.

TABLE V

ANALYSIS OF COVARIANCE-SUMMARY

ALL SCORES

Source	Sums of Squares	df	Mean Squares	F
Subjects	9,478,481.54	23	412,107.89	25.27 * **
Subjects within trials	1,157,788.19	71	16,306.88	1.43
Tests	1,507,700.97	3	502,566.99	43.99 * **
Subjects x Tests	4,915,230.12	69	71,235.22	6.24 * **
Residual	2,455,970.40	215	11,431.12	
Total	19,515,171.22	381		

* significant at .05 level
** significant at .01 level

	df	.05	.01
	23,71	1.68	2.11
F =	3,215	2.65	3.88
	69,215	1.39	1.58

In order to account for differences of knee angle and the effect of these differences on test scores an analysis of covariance was computed in which knee angle was treated as the covariate. The results

of this analysis are presented in Table V. When analysis of covariance was used on all scores the F values for subjects, tests, and subjects by tests interaction were still highly significant. The amount of correlation between the lift score and angle change is expressed in the correlation coefficients presented in Table VI

TABLE VI

CORRELATION COEFFICIENTS FOR TEST AND ANGLE CHANGE

Test	Correlation Coefficient
A	0.43
B	0.27
C	0.42
D	0.42

The amount of difference in test scores that can be accounted for by differences in knee angle is shown in the correlation coefficients between tests and angle changes.

Significant differences among test means have been found using all scores in analyses of variance and covariance. However, maximum strength scores are normally used when the leg lift is administered as a part of the P.F.I. battery. Furthermore, results of statistical analysis may depend upon which data are used. For these two reasons analyses of variance and covariance were computed using maximum strength scores. The means for maximum scores are presented in Table VII

TABLE VII

MAXIMUM SCORE MEANS

	TESTS			
	A	B	C	D
Means	1104.16	926.71	849.00	986.88

Once again the definite pattern can be observed in the ascending order of the means, Test C, Test B, Test D, Test A. The significance of the observed differences among means in Table VII was tested by using analysis of variance with maximum scores. The results of that analysis are displayed in Table VIII.

TABLE VIII

ANALYSIS OF VARIANCE-SUMMARY

MAXIMUM SCORES

Source	Sums of Squares	df	Mean Squares	F
Tests	834,161.71	3	278,053.90	3.82 * **
Residual	6,705,080.92	92	72,881.31	
Total	7,539,242.63	95		

* significant at .05 level
** significant at .01 level

	df	.05	.01
F=	3,92	2.72	4.04

The F value for tests as determined by analysis of variance using maximum strength scores exceeded the .05 level of confidence.

To determine whether the significant differences among the four test methods using maximum scores could be accounted for on the

basis of differences among them in knee angle at which they were produced an analysis of covariance was carried out. The results of the analysis of covariance using maximum scores are shown in Table IX.

TABLE IX

ANALYSIS OF COVARIANCE-SUMMARY

MAXIMUM SCORES

Source	Sums of Squares	df	Mean Squares	F
Tests	525,925.00	3	175,308.33	2.69
Residual	5,920,477.07	91	65,060.19	
Total	6,446,402.07	94		

	df	.05	.01
F =	3,91	2.72	4.04

As shown in Table IX the analysis of covariance F value for tests is not significant at the .05 level. However, the F value obtained is large enough to warrant reporting that it is approaching significance at the .05 level of confidence.

Once again it is of interest to determine whether results of the analyses being used are determined by the data selected. Up until this point all scores and maximum scores have been used in analyses of variance and covariance. The general means of Table III represent the averages for all trials. Since differences between the means for average scores are observed in Table III analyses of variance and covariance were computed using average scores. A summary of the results of these analyses is presented in Tables X and XI.

TABLE X

ANALYSIS OF VARIANCE-SUMMARY

AVERAGE SCORES

Source	Sums of Squares	df	Mean Squares	F
Tests	657,046.27	3	219,015.42	4.76 * **
Residual	4,231,846.14	92	45,998.33	
Total	4,888,892.41	95		

* significant at .05 level
** significant at .01 level

	df	.05	.01
F=	3,92	2.72	4.04

Averages of the four trials allowed on each test were also used in analysis of variance. A summary of this analysis appears in Table X. The F value for tests using average scores in analysis of variance was highly significant.

To determine whether knee angle was influencing the significant differences among tests using average scores, an analysis of covariance was carried out. A summary of the analysis of covariance using average scores is presented in Table XI. When knee angle changes were treated as the covariate in analysis of covariance using average scores the significance of the F value still exceeded the .05 level.

Significant differences among means were found using analyses of variance with all scores, maximum scores, and average scores. On the basis of these differences between treatment means using the Newman-Keuls method (4:80-84). Unadjusted means for maximum scores, adjusted means for maximum scores, unadjusted means for average scores, and adjusted means for average scores were used. The results of the

tests on ordered pairs of means appear in Tables XII, XIII, XIV, and XV.

TABLE XI

ANALYSIS OF COVARIANCE-SUMMARY

AVERAGE SCORES

Source	Sums of Squares	df	Mean Squares	F
Tests	411,117.53	3	137,039.18	3.46 *
Residual	3,599,702.70	91	39,557.17	
Total	4,010,820.23	94		

* significant at .05 level

		df	.05	.01
F	=	3,91	2.72	4.04

TABLE XII

NEWMAN-KEULS TESTS ON ALL ORDERED PAIRS OF MEANS

UNADJUSTED MEANS-MAXIMUM SCORES

Order	1	2	3	4
Treatments in Order	C	B	D	A
Means	849.00	926.71	986.88	1104.16
C	-	77.71	137.88	255.16 *
B		-	60.17	177.46
D			-	117.29
A				-
Truncated Range r		2	3	4
q.95(r,91)		2.82	3.38	3.72
q.95(r,91) MSerror/N		155.12	186.26	204.72

* difference significant when greater than Truncated Range r for that order.

TABLE XIII

NEWMAN-KEULS TESTS ON ALL ORDERED PAIRS OF MEANS

ADJUSTED MEANS-MAXIMUM SCORES

Order	1	2	3	4
Treatments in order	C	B	D	A
Means	867.1331	928.68	1005.40	1065.54
C	-	61.55	138.27	198.41 *
B		-	76.72	136.86
D			-	60.13
A				-
Truncated Range r		2	3	4
q.95(r,91)		2.82	3.38	3.72
q.95(r,91) $\sqrt{MSerror/N}$		146.56	175.98	193.42

* difference significant when greater than Truncated Range r for that order

As indicated in Tables XII and XIII the tests on all ordered pairs of means using unadjusted means for maximum scores and adjusted means for maximum scores revealed significant differences between Test A and Test C only.

TABLE XIV

NEWMAN-KEULS TESTS ON ALL ORDERED PAIRS OF MEANS

UNADJUSTED MEANS-AVERAGE SCORES

Order	1	2	3	4
Treatments in order	C	B	D	A
Means	756.20	819.98	847.72	982.98
C	-	63.78	91.52	226.78 *
B		-	77.74	163.00 *
D			-	135.26
A				-
Truncated Range r		2	3	4
q.95(r,91)		2.82	3.38	3.72
q.95(r,91) $\sqrt{MSerror/N}$		123.24	147.97	162.64

* difference significant when greater than Truncated Range r for that order

TABLE XV

NEWMAN-KEULS TESTS ON ALL ORDERED PAIRS OF MEANS

ADJUSTED MEANS-AVERAGE SCORES

Order		1	2	3	4
Treatments in order		C	B	D	A
Means		772.99	812.35	872.55	948.98
	C	-	39.36	99.55	175.99 *
	B		-	60.19	136.63
	D			-	76.43
	A				-
Truncated Range r			2	3	4
q.95(r,91)			2.82	3.38	3.72
q.95(r,91) $\sqrt{\text{MSerror}/N}$			114.28	137.22	150.82

* difference significant when greater than Truncated Range r for that order

The results of the Newman-Keuls tests using unadjusted and adjusted average score means appear in Tables XIV and XV. Using the unadjusted means for average scores significant differences were found between Test A and Test C and between Test A and Test B. However, when the adjusted means for average scores were used a significant difference appeared between Test A and Test C only.

Despite the fact that significant differences were found only between Test A and Test C, and in one case between Test A and Test B, it is worthy of mention that observed differences between means are considerable, in many cases being greater than one hundred pounds. Once again the presence of the pattern of ascending means in the order of Test C, Test B, Test D, and Test A is noted.

The influence of changes in knee angle on test scores has been considered in the correlation coefficients of Table VI and with the analyses of covariance using all scores, maximum scores, and average

scores. None of these, however, indicate whether there are differences in knee angle among test methods. To determine whether there are significant differences among the means of the test angles an analysis of variance was carried out.

The angle means are shown for each test in Table XVI.

TABLE XVI

ANGLE MEANS FOR TESTS

Test	Mean
A	21.65
B	19.11
C	16.77
D	16.00

The differences among means that can be observed in the data of Table XVI seem to be of two kinds. The first appears to be due to the type of belt used for the tests. The larger means appear for Test A and Test B. Both of these tests used the traditional belt. The smaller angle changes appear for Test C and Test D where the experimental belt was used. Secondly, there appears to be a difference between the angle changes for Test A and Test B. Test A, where there was no restriction of lunging, has the greater mean change in angle. The smaller changes for the two tests appeared with Test B where lunging was controlled.

To determine whether the observed differences among the angle means were significant an analysis of variance was carried out. A summary of this analysis is presented in Table XVII.

TABLE XVII

ANALYSIS OF VARIANCE-SUMMARY

KNEE ANGLE CHANGES

Source	Sums of Squares	df	Mean Squares	F
Tests	1868.06	3	622.69	28.97 * **
Subjects	11569.81	23	503.04	23.40 * **
Subjects x Tests	11720.13	69	169.86	7.90 * **
Error	6190.75	288	21.50	
Total	31348.75	383		

* significant at .05 level
** significant at .01 level

	df	.05	.01
	3,288	2.60	3.78
F=	23,288	1.52	1.79
	69,288	1.30	1.44

When mean angle changes were used in analysis of variance highly significant F values were obtained for tests, subjects, and subjects by tests interaction. The F value for tests indicates that the observed differences among the means for angles as presented in Table XIII are, in fact, highly significant. No particular cognizance is taken of the fact that significant differences appear among subjects since these differences may be expected due to individual differences among subjects. The differences among subjects do help to reduce the error term. The subjects by tests interaction indicates that the performances of some subjects are influenced by a particular test method.

Discussion

Tests. With only one exception the analyses of variance and covariance yielded values of F which were significant beyond the .05 level. The analysis of covariance using maximum scores was the exception where the F value approached the .05 level of confidence but was not significant at the .05 level. An F of 2.69 was obtained when a value of 2.72 was required. The data in Table IV not only reveal differences between test methods but also reveal the fact that some individuals were affected in performance by a particular testing method. Such findings are similar to those of Hubbard and Mathews (2:38) who also compared different leg lift test methods.

Because maximum strength scores are usually recorded in the administration of the P.F.I. test battery further comparisons were made using maximum strength scores for the four tests. Once again analyses of variance and covariance were used. The F value for tests in the analysis of variance was significant. When changes in knee angle were treated as the covariate in the analysis of covariance the F value for tests was not significant at the .05 level.

A further comparison was made using the averages of the four trials for each test. For this condition the F values for tests were significant using both analysis of variance and analysis of covariance.

Based on the results of the above analyses it can be seen that there are significant differences among testing methods, and that a pattern exists in the ascending order of the means. The low to high ranking of means is always Test C, Test B, Test D, Test A. This ranking holds true for all scores, maximum scores, and average scores.

On the basis of these results an appraisal consisting of the

Newman-Keuls Test on all ordered pairs of means was used to determine which testing methods differed. Means for maximum scores and average scores were used for comparison. Further comparisons were made using the adjusted means resulting from the analyses of covariance. When the Newman-Keuls test was used the only differences between means that were large enough to be significant were those for Test A and Test C. An exception was found using the unadjusted average score means. On this test both Test B and Test C differed from Test A.

Knee Angle. According to Carpenter (1:71) knee angle has an effect on the performance of the leg lift test. All subjects in the present study began lifting at an angle of 120 degrees and changes in knee angle were recorded throughout the lifts. Changes in knee angle were treated as the covariate in the analyses of covariance in an attempt to control statistically the effects of knee angle change on performance. Even after holding knee angle constant the F values for tests were significant in the analyses of covariance using all scores and average scores.

Variations in body height and weight as well as belt construction allowed changes to occur in knee angle during the execution of the lifting movements. An analysis of variance was carried out on knee angle changes to determine whether significant differences existed among the knee angle means. Differences in knee changes among tests were highly significant indicating that knee angle varied with test method. The smallest changes in knee angle were obtained on tests using the experimental belt.

<u>Summary</u>. Highly significant differences were found among methods and among subjects when all scores were used in analysis of variance and analysis of covariance. When maximum scores were used significant differences among tests were found only with analysis of variance. When analysis of covariance was used with maximum scores the F value for tests approached significance at the .05 level but was not large enough to be significant. When average strength scores were used significant differences among tests were found using both analyses of variance and covariance.

Although significant differences among tests were found using analyses of variance and covariance when the Newman-Keuls test on all ordered pairs of means was used a significant difference was found only between Test A and Test C. In one case, using unadjusted means for average scores, differences were also found between Test A and Test B. It was noted that means always ascended from low to high in the order of Test C, Test B, Test D, and Test A.

Significant differences were found for knee angles among tests.

In the present study the least error of measurement occurred with Test C, where the experimental belt was employed to eliminate the use of hands, and to prevent slippage of the belt, and where lunging was prevented by the vertical board.

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CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study was to investigate differences in leg lift scores when the traditional bar and belt were used and when an experimental bar and belt were used which eliminated the need for a subject to use his hands. A sub-problem involved the possible effects of changes in knee angle on lift scores.

Twenty-four first year male students from the University of Alberta volunteered to serve as subjects. They were randomly assigned to twenty-four different testing orders so that no testing order was duplicated.

Each subject took four different leg lift tests and was allowed four trials on each test. Test A involved the use of the traditional bar and belt and the experimental leg dynamometer with no restriction of forward or backward movement. Test B was the same as Test A with the exception that forward and backward lunging were inhibited. Test C involved the use of the experimental belt and bar, the experimental leg dynamometer, and the restriction of lunging as in Test B. The subjects were not allowed to grasp the bar in any way on Test C. Test D was identical to Test C except for Test D the subjects were instructed to grasp the bar with their hands.

Analyses of variance and covariance yielded significant F values for test methods and for subjects. Use of the Newman-Keuls test on all ordered pairs of means resulted in significant differences appearing between Test A and Test C.

The following conclusions are justifiable on the basis of the statistical analysis:

1. Differences between Test A, in which the traditional belt was used with no restriction of lunging, and Test C, in which the experimental belt was used without hands with restriction of lunging, were significant.

2. Differences between Test A and Test C are still significant when effects of knee angle changes are statistically controlled.

3. Significant differences in knee angle change were found among tests with the smallest change in angle occurring with the experimental belt.

4. Of the four tests, Test C was found to be the most reliable as reported in the reliability study using Tables I and II.

Recommendations

It is recommended that the experimental belt be used without hands as in Test C with the traditional leg dynamometer for the purpose of making further comparisons with the traditional method.

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APPENDIX A

RAW DATA

TEST A

STRENGTH SCORES AND KNEE ANGLE CHANGES

STRENGTH SCORE (POUNDS)					KNEE ANGLE CHANGE (DEGREES)				
R					S				
Subject	Trial				Subject	Trial			
	1	2	3	4		1	2	3	4
1	900	1113	1021	1078	1	17	21	17	22
2	1593	1613	1425	1688	2	48	52	36	44
3	1050	1138	1013	975	3	18	24	22	20
4	723	793	793	863	4	14	22	16	16
5	525	750	738	1000	5	12	18	18	24
6	1013	1050	850	863	6	20	20	15	12
7	1200	1338	1275	1450	7	18	19	24	26
8	1125	1038	1000	975	8	24	21	20	22
9	450	500	525	588	9	40	20	28	28
10	513	433	450	488	10	10	9	8	6
11	1013	763	788	815	11	23	10	12	14
12	1253	1163	1175	975	12	26	18	26	18
13	1088	863	1500	1238	13	16	13	19	26
14	1163	788	938	958	14	28	16	16	16
15	1218	1113	1245	975	15	16	14	16	10
16	1075	788	1125	1125	16	18	6	16	16
17	600	945	965	875	17	42	32	46	28
18	1050	1020	825	938	18	24	28	22	24
19	813	650	825	825	19	26	22	26	30
20	988	970	925	1088	20	21	20	19	22
21	993	1013	1145	1143	21	17	17	16	16
22	1163	1350	1040	1180	22	24	34	26	21
23	1200	1088	1175	1275	23	28	34	34	34
24	725	750	788	975	24	18	16	16	15

TEST B

STRENGTH SCORES AND KNEE ANGLE CHANGES

STRENGTH SCORE (POUNDS)					KNEE ANGLE CHANGE (DEGREES)				
R					S				
Subject	Trial				Subject	Trial			
	1	2	3	4		1	2	3	4
1	1000	975	975	788	1	14	12	10	14
2	1275	663	988	995	2	38	18	18	18
3	768	613	617	468	3	12	10	10	10
4	825	813	863	938	4	10	14	8	14
5	825	730	780	1103	5	20	22	18	32
6	788	845	813	855	6	12	10	8	12
7	863	825	863	900	7	32	8	10	10
8	768	825	1068	955	8	36	31	35	26
9	150	175	195	230	9	18	20	27	24
10	438	388	375	450	10	16	16	12	16
11	583	735	735	723	11	16	25	12	28
12	750	543	543	575	12	20	14	10	14
13	1013	768	838	1038	13	12	10	10	24
14	663	625	750	750	14	16	12	14	10
15	900	800	925	1125	15	20	16	20	16
16	900	1073	1200	1145	16	28	26	26	23
17	845	730	613	875	17	24	24	18	22
18	813	838	825	845	18	14	9	9	12
19	845	838	813	878	19	16	14	19	18
20	938	888	825	900	20	16	24	18	24
21	983	1013	993	1120	21	16	18	18	16
22	863	733	830	1050	22	24	24	23	26
23	870	1200	1375	1313	23	14	22	34	36
24	875	920	825	975	24	32	44	60	24

TEST C

STRENGTH SCORES AND KNEE ANGLE CHANGES

STRENGTH SCORE (POUNDS)					KNEE ANGLE CHANGE (DEGREES)				
R					S				
Subject	Trial				Subject	Trial			
	1	2	3	4		1	2	3	4
1	938	863	850	955	1	16	20	12	13
2	863	955	950	975	2	10	14	14	12
3	963	800	750	750	3	12	14	19	17
4	600	505	488	630	4	4	10	4	4
5	913	883	938	1038	5	22	20	19	18
6	715	900	870	938	6	11	16	14	13
7	1138	788	788	808	7	20	12	11	8
8	950	900	713	813	8	24	22	14	20
9	465	525	725	638	9	24	28	16	20
10	313	338	375	420	10	6	8	8	10
11	638	713	788	863	11	13	14	16	16
12	913	800	900	995	12	22	18	14	22
13	430	413	418	413	13	18	11	16	18
14	463	513	618	750	14	16	24	16	16
15	813	893	948	988	15	18	14	12	14
16	750	875	888	918	16	16	18	14	24
17	938	863	975	1013	17	42	38	48	60
18	575	638	738	813	18	18	14	20	22
19	663	663	675	693	19	8	8	11	11
20	508	550	658	700	20	12	12	16	14
21	883	825	1088	1098	21	11	12	18	14
22	1050	868	900	1083	22	36	27	28	42
23	675	638	705	525	23	8	12	15	16
24	483	525	563	595	24	6	11	9	12

TEST D

STRENGTH SCORES AND KNEE ANGLE CHANGES

STRENGTH SCORE (POUNDS)					KNEE ANGLE CHANGE (DEGREES)				
R					S				
Subject	Trial				Subject	Trial			
	1	2	3	4		1	2	3	4
1	925	1025	918	1188	1	10	12	12	16
2	1400	1188	1210	2348	2	18	14	14	18
3	788	720	738	738	3	10	14	14	12
4	875	875	875	888	4	10	10	10	12
5	750	850	945	843	5	14	18	18	18
6	733	720	793	800	6	8	10	12	10
7	713	713	720	750	7	11	8	12	12
8	825	825	788	875	8	17	16	24	14
9	905	580	613	625	9	12	12	11	10
10	500	488	505	618	10	8	10	9	12
11	600	525	618	655	11	8	8	5	6
12	545	563	713	695	12	12	12	12	8
13	713	685	688	788	13	8	10	10	10
14	738	825	583	650	14	24	20	12	10
15	1258	1005	938	1038	15	26	23	20	10
16	803	963	983	1088	16	12	12	14	12
17	1068	938	838	838	17	29	26	18	20
18	835	600	675	1040	18	12	6	10	12
19	788	825	800	808	19	20	38	22	22
20	563	450	675	788	20	11	8	14	18
21	993	1013	988	1163	21	16	16	16	18
22	1258	1125	1188	1150	22	48	44	38	36
23	1018	943	1248	713	23	20	18	22	14
24	713	815	863	825	24	24	34	36	34

[illegible]

MAXIMUM STRENGTH SCORES AND KNEE ANGLE CHANGES

	STRENGTH SCORES MAXR				KNEE ANGLE CHANGES MAXS			
SUBJECT	TEST A	TEST B	TEST C	TEST C	TEST A	TEST B	TEST C	TEST D
1	1113	1000	955	1188	21	14	13	16
2	1688	1275	975	2348	44	38	12	18
3	1138	768	963	788	24	12	12	10
4	863	938	630	888	16	14	4	12
5	1000	1103	1038	945	24	32	18	18
6	1050	855	938	800	20	12	13	10
7	1450	900	1138	750	26	10	20	12
8	1125	1068	950	875	24	35	24	14
9	588	230	725	905	28	24	16	12
10	513	450	420	618	10	16	10	12
11	1013	735	863	655	23	12	16	6
12	1253	750	995	713	26	20	22	12
13	1500	1038	430	788	19	24	18	10
14	1163	750	750	825	28	10	16	20
15	1245	1125	988	1258	16	16	14	26
16	1125	1200	918	1088	16	26	24	12
17	965	875	1013	1068	46	22	60	29
18	1050	845	813	1040	24	12	22	12
19	825	878	693	825	30	18	11	38
20	1088	938	700	788	22	16	14	18
21	1145	1120	1098	1163	16	16	14	18
22	1350	1050	1083	1258	34	26	42	48
23	1275	1375	705	1248	34	34	15	22
24	975	975	595	863	15	24	12	36

AVERAGE STRENGTH SCORES AND KNEE ANGLE CHANGES

	STRENGTH SCORES AVER				KNEE ANGLE CHANGES AVES			
SUBJECT	TEST A	TEST B	TEST C	TEST D	TEST A	TEST B	TEST C	TEST D
1	1028.00	934.50	901.50	1014.00	19.24	12.50	15.25	12.50
2	1579.75	980.25	935.75	1536.50	45.00	23.00	12.50	16.00
3	1044.00	616.50	815.75	746.00	21.00	10.50	15.50	12.50
4	793.00	859.75	555.75	878.25	17.00	11.50	5.50	10.50
5	753.25	859.50	943.00	847.00	18.00	23.00	19.75	17.00
6	944.00	825.25	855.75	761.50	16.75	10.50	13.50	10.00
7	1315.75	862.75	880.50	724.00	21.75	15.00	12.75	10.75
8	1034.50	904.00	844.00	828.25	21.75	32.00	20.00	17.75
9	515.75	187.50	588.25	680.75	29.00	22.25	22.00	11.25
10	471.00	412.75	361.50	527.75	8.25	15.00	8.00	9.75
11	844.75	694.00	750.50	599.50	14.75	20.25	14.75	6.75
12	1141.50	602.75	902.00	629.00	22.00	14.50	19.00	11.00
13	1172.25	914.25	418.50	718.50	18.50	14.00	15.75	9.50
14	961.75	697.00	586.00	699.00	19.00	13.00	18.00	16.50
15	1137.75	937.50	910.50	1059.75	14.00	18.00	14.50	19.75
16	1028.25	1079.50	857.75	959.25	14.00	25.75	18.00	12.50
17	846.25	765.75	947.25	920.50	37.00	22.00	47.00	23.25
18	958.25	830.25	691.00	787.50	24.50	11.00	18.50	10.00
19	778.25	843.50	673.50	805.25	26.00	16.75	9.50	25.50
20	992.75	887.75	604.00	619.00	20.50	20.50	13.50	12.75
21	1073.50	1027.25	973.50	1039.25	16.50	17.00	13.75	16.50
22	1183.25	869.00	975.25	1180.25	26.25	24.25	33.25	41.50
23	1184.50	1189.50	635.75	980.50	32.50	26.50	12.75	18.50
24	809.50	898.75	541.50	804.00	16.25	40.00	9.5	32.00

APPENDIX B

FORMULAS

STANDARD ERROR OF MEASUREMENT FORMULA

$$S_m = S_t \sqrt{1 - r}$$

Where:

S_m = Standard error of Measurement.

S_t = Standard Deviation of Scores.

r = Reliability Coefficient.

Tolerance = $2 \times S_m$

APL FORMULA   ANALYSIS OF VARIANCE   ALL SCORES

RAW STRENGTH SCORES ARE STORED UNDER CODE LETTER   R
RAW KNEE ANGLE SCORES ARE STORED UNDER CODE LETTER   S

Y IS A 4×4×24 MATRIX (TRIALS×TESTS×SUBJECTS)

```
Y←R
X←S

GBY←(+/+/+/Y)÷4×4×24
ABY←(+/[1]+/[1]Y)÷4×4
BBY←(+/[1]+/Y)÷4×24
PBY←(+/Y)÷24
ABBY←(+/[1]Y)÷4
GBX←(+/+/+/X)÷4×4×24
ABX←(+/[1]+/[1]X)÷4×4
BBX←(+/[1]+/X)÷4×24
PBX←(+/X)÷24
ABBX←(+/[1]X)÷4
AYY←N×Q×+/(ABY-GBY)*2
PYY←(P×+/+/(PBY-GBY)*2)-AYY
BYY←N×P×+/(BBY-GBY)*2
ABYY←(N×+/+/(ABBY-GBY)*2-(AYY+BYY)
EYY←SYY-(AYY+BYY+PYY+ABYY)
SYY←+/+/+/(Y-GBY)*2
AXX←N×Q×+/(ABX-GBX)*2
PXX←(P×+/+/(PBX-GBX)*2)-AXX
BXX←N×P×+/(BBX-GBX)*2
ABXX←(N×+/+/(ABBX-GBX)*2-(AXX+BXX)
SXX←+/+/+/(X-GBX)*2
EXX←SXX-(AXX+BXX+PXX+ABXX)
AYX←N×Q×+/(ABX-GBX)×(ABY-GBY)
PYX←(P×+/+/(PBX-GBX)×(PBY-GBY))-AYX
BYX←N×P×+/(BBX-GBX)×(BBY-GBY)
ABYX←(N×+/+/(ABBX-GBX)×(ABBY-GBY))-(AYX+BYX)
SYX←+/+/+/(X-GBX)×(Y-GBY)
EYX←SYX-(AYX+BYX+PYX+ABYX)
```

APL FORMULA   ANALYSIS OF COVARIANCE   ALL SCORES

```
PPYY←PYY-(PXY*2)÷PXX
APYY←AYY+PYY-((((AXY+PXY)*2)÷(AXX+PXX))+PPYY)
EPYY←EYY-(EXY*2)÷EXX
BPYY←BYY+EYY-((((BXY+EXY)*2)÷(BXX-EXX))+EPYY)
ABPYY←ABYY+EYY-((((ABXY+EXY)*2)÷(ABXX+EXX))+EPYY)
```

APL FORMULA   ANALYSIS OF VARIANCE   MAXIMUM SCORES

MAXIMUM RAW STRENGTH SCORES ARE STORED UNDER CODE MAXR
MAXIMUM RAW ANGLE SCORES ARE STORED UNDER CODE MAXS

```
XBJ←(+/MAXR)÷24
XB←(+/XBJ)÷4
YBJ←(+/MAXS)÷24
YB←(+/YBJ)÷4
TXX←4×+/(XBJ-XB)*2
TXY←4×+/(XBJ-XB)×(YBJ-YB)
TYY←4×+/(YBJ-YB)*2
SXX←+/+/(MAXR-XB)*2
SXY←+/+/(MAXR-XB)×(MAXS-YB)
SYY←+/+/(MAXS-YB)*2
EXX←SXX-TXX
EYY←SYY-TYY
MST←TXX÷3
MSE←EXX÷92
F←MST÷MSE
```

APL FORMULA   ANALYSIS OF COVARIANCE   MAXIMUM SCORES

```
SPXX←SXX-(SXY*2)÷SYY
EPXX←EXX-(EXY*2)÷EYY
TXXR←SPXX-EPXX
MSPT←TXXR÷3
MSPE←EPXX÷91
FP←MSPT÷MSPE
```

APL FORMULA   ANALYSIS OF VARIANCE   AVERAGE SCORES

AVERAGE STRENGTH SCORES ARE STORED UNDER CODE   AVER
AVERAGE ANGLE SCORES ARE STORED UNDER CODE   AVES

```
LBJ←(+/AVER)÷24
LB←(+/LBJ)÷4
RBJ←(+/AVES)÷24
RB←(+/RBJ)÷4
VXX←4×+/(LBJ-LB)*2
VXY←4×+/(LBJ-LB)×(RBJ-RB)
VYY←4×+/(RBJ-RB)*2
WXX←+/+/(AVER-LB)*2
WXY←+/+/(AVER-LB)×(AVES-RB)
WYY←+/+/(AVES-RB)*2
DXX←WXX-VXX
DXY←WXY-VXY
DYY←WYY-VYY
NST←VXX÷3
NSE←DXX÷92
G←NST÷NSE
```

APL FORMULA   ANALYSIS OF COVARIANCE   AVERAGE SCORES

```
WPXX←WXX-(WXY*2)÷WYY
DPXX←DXX-(DXY*2)÷DYY
VXXR←WPXX-DPXX
NSPT←VXXR÷3
NSPE←DPXX÷91
GP←NSPT÷NSPE
```

APPENDIX C

TESTING ORDERS

TESTING ORDERS: TESTS, A; B; C; D.
TRIALS, 4

1.	A	B	C	D	13.	C	D	A	B
2.	A	C	B	D	14.	C	D	B	A
3.	A	C	D	B	15.	C	B	A	D
4.	A	B	D	C	16.	C	B	D	A
5.	A	D	C	B	17.	C	A	B	D
6.	A	D	B	C	18.	C	A	D	B
7.	B	C	D	A	19.	D	A	B	C
8.	B	C	A	D	20.	D	A	C	B
9.	B	A	C	D	21.	D	C	A	B
10.	B	A	D	C	22.	D	C	B	A
11.	B	D	A	C	23.	D	B	A	C
12.	B	D	C	A	24.	D	B	C	A

Test A: Traditional Method, load cell, recorders, electrogoniometer.

Test B: Traditional Method, preventing back lunge, load cell, electro-goniometer, recorders.

Test C: Experimental Method, new belt, preventing back lunge, recorders, electro-goniometer.

Test D: Experimental Method, new belt, preventing back lunge, recorders, electro-goniometer, <u>with hands</u>.

APPENDIX D

DATA COLLECTION SHEET

DATA SHEET

NAME ______________________________ TESTING ORDER ____ ____ ____ ____

AGE (yrs. & mos.) ______ _____ WEIGHT ________ HEIGHT ____________

FACULTY ___________________ YEAR _____________

TEST ______ DATE _______ TIME ______ SCORES FOR TRIALS 1_____ ANGLE____
2_____ ____
3_____ ____
4_____ ____

TEST______ DATE________ TIME______ SCORES FOR TRIALS 1_____ ANGLE____
2_____ ____
3_____ ____
4_____ ____

TEST______ DATE________ TIME______ SCORES FOR TRIALS 1_____ ANGLE____
2_____ ____
3_____ ____
4_____ ____

TEST______ DATE________ TIME______ SCORES FOR TRIALS 1_____ ANGLE____
2_____ ____
3_____ ____
4_____ ____

DATE:

TEST A		TEST B		TEST C		TEST D	
Best	Ave.	Best	Ave.	Best	Ave.	Best	Ave.

APPENDIX E

ANTHROPOMETRICAL DATA

ANTHROPOMETRICAL DATA

SUBJECT	AGE (yrs. and mos.)	WEIGHT (lbs.)	HEIGHT (inches)
1	18, 4	177	74.5
2	18, 7	187	72.0
3	17,10	204	76.0
4	18, 2	142	72.0
5	21, 7	130	65.0
6	24, 6	161	69.5
7	18, 6	142	68.0
8	19, 2	150	70.5
9	21, 2	108	63.5
10	20, 6	136	71.0
11	18, 2	136	68.0
12	20, 2	143	73.0
13	18, 6	167	72.5
14	18, 4	156	69.0
15	20, 6	190	67.0
16	19,11	158	67.0
17	18, 3	159	73.0
18	18, 3	130	69.0
19	20,11	142	67.0
20	19,10	171	72.0
21	19,11	156	72.0
22	19, 9	176	70.0
23	18, 9	170	70.0
24	18, 3	144	65.0

APPENDIX F

CALIBRATION OF THE ELECTROGONIOMETER

CALIBRATION OF THE ELECTROGONIOMETER

The electrogoniometer was calibrated frequently during the testing period according to the procedures described in Chapter III.

Frequent calibration enabled the experimenter to read the changes in knee angle by comparing the recordings from the performance with the calibration chart.